Modeling and Simulation of Non-Isothermal Gas-Assisted Injection Molding For Non-Newtonian Fluids

Panayiotis K. Kolliopoulos, Dr. Kurt W. Koelling

William G. Lowrie Department of Chemical & Biomolecular Engineering, The Ohio State University, 140 W. 19th Ave., Columbus, OH, 43210

INTRODUCTION

Gas-assisted injection molding (GAIM) process is the injection of a molten resin into a mold cavity simultaneously or followed by the injection of pressurized gas into the resin to fill out the mold cavity and form a hollow pocket(s) in the resin (Loren, 1993). The gas is then used to transit the packing pressure to compensate for polymer shrinkage and is vented out just prior to opening the mold

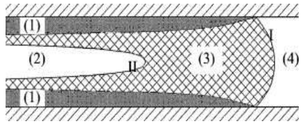


Figure 1: Schematic notation for flow regions and their interface in gas-assisted injection molding: (1) the solid frozen layer, (2) the penetration gas, (3) the deforming viscous melt, (4) the unfilled cavity, (I) the melt front, (II) the gas front. (Jianhui Li, 2009)

There are numerous advantages to GAIM, such as:

- using less plastic material and reducing the weight
- increasing the strength and rigidity of the part
- improving the part appearance
- increasing the design options

Some applications of GAIM are:

- appliance handles,
- medical equipment housings,
- automotive parts and many more

MOTIVATION

Due to the fact that mold design and process control are so critical and difficult, computer simulation of GAIM is necessary. The GAIM simulation software that is available is MOLDFLOW, MOLDEX3D and others. All of this software is based on a midplane model or a 3D model. The disadvantage of the midplane model is that a second modelling is inevitable. The 3D model requires a full-scale three-dimensional discretization of thin parts which results in unsustainable computing time and instability of calculation (Jianhui Li, 2009).

Therefore, the purpose of this research project is to develop a GAIM computer simulation that can effectively predict the polymer coating thickness in a non-isothermal system at both high and low capillary numbers.

METHODS

Temperature Profile Calculation

The governing equations are depicted below and then manipulated by utilizing the finite difference method:

- Heat transfer outside the tube wall

$$-k_s \left.\frac{\partial T}{\partial r}\right|_{r=R_{02}} = h(T_w - T_B)$$

Where:

$$h = \frac{k_f}{D}\left\{\left[\left(\left((Nu_{lam}^{1.07} + Nu_{cond}^{1.07})^{\frac{1}{1.07}}\right)^6 + (Nu_{turb})^6\right)^{\frac{1}{6}}\right]^3 + Nu_{force}^3\right\}^{\frac{1}{3}}$$

- Heat transfer inside the stainless steel tube wall

$$\frac{\partial T^S}{\partial t} = \frac{k_s}{\rho_s C_{p,s}}\left(\frac{\partial^2 T^S}{\partial r^2} + \frac{1}{r}\frac{\partial T^S}{\partial r}\right)$$

- Heat transfer inside the polymer

$$\frac{\partial T}{\partial t} = \frac{k_p}{\rho_p C_{p,p}}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right)$$

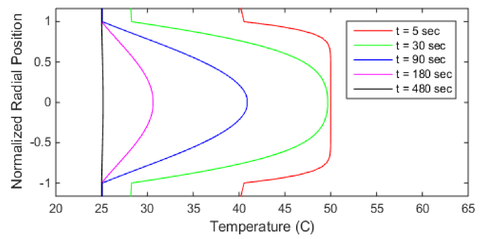


Figure 2: Normalized Radial Position versus Temperature at different Delay Times

Viscosity Calculation

Once the temperature profiles were calculated, the temperature dependent viscosity could be obtained from the following equation.

$$\eta = A \exp\left(\frac{\Delta H}{RT(r)}\right)$$

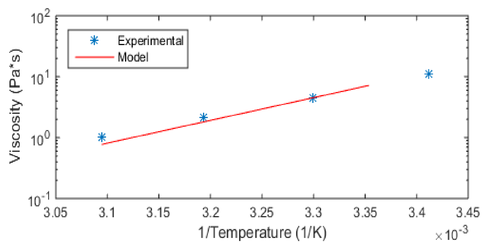


Figure 3: Comparison of Model Calculated viscosity and experimental viscosity data.

Momentum Balance for Velocity Profile Calculation

Thus by utilizing the calculated viscosity, the temperature profiles were calculated from the momentum balance depicted below:

$$\frac{\partial}{\partial r}\left(r\eta\frac{\partial u_z}{\partial r}\right) = \frac{r\Delta P}{L}$$

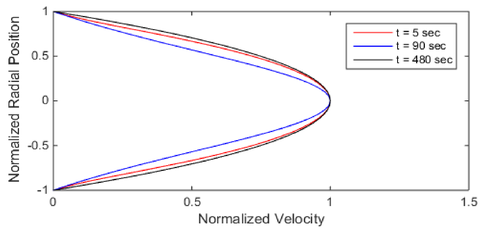


Figure 4: Normalized Radial Position versus Normalized Velocity at different Delay Times

Normalized Velocity Calculation

This part of the method is what deviates from the conventional way used in previous simulation models.

By making the control volume assumption depicted bellow:

$$\int_0^{R_{01}} 2\pi * r * u * dr = \int_0^{R_x} 2\pi * r * u_x * dr$$

The normalized velocity can be calculated and then by assuming that the normalized velocity is in the following form:

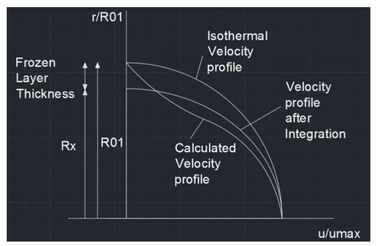
$$u_x = \left(1 - \left(\frac{r}{R_x}\right)^2\right)^{1/2}$$

The radius of the parabolic shape can be solved for.

Fractional Coverage Calculation

Once the radius is determined the fractional coverage can be calculated using:

$$m = 1 - 0.4\left(\frac{R_x}{R_{01}}\right)^2$$



RESULTS

The method depicted above was implemented in MATLAB for high capillary numbers and compared to the method used by Yijie Wang and the experimental data collected by Minesh R. Tendulkar which was also at high capillary numbers.

The two models were compared at a number of temperature gradients utilizing a variety of tubes. Below is one comparison with one temperature gradient and a specific tube size.

Model Comparison when Cooling fluid Temperature is 25°C and the Polymer Temperature is 50°C

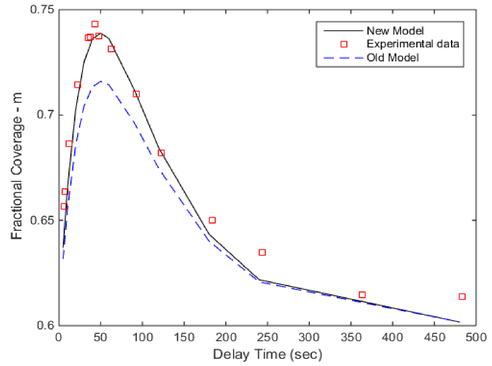


Figure 5: Experimental, old and new model calculation results of fractional coverage as a function of time, 1/2" tube, temperature gradient from 50°C to 25°C

CONCLUSIONS

- The New Simulation Model more accurately predicts the maximum fractional coverage along with the correct delay time.
- The run time of the simulation program has been reduced from 40 min to 1 min.

FUTURE WORK

- Collect more experimental data, specifically at low capillary numbers
- Extend simulation model to low capillary numbers
- Develop MATLAB GUI program that will be able to model different polymers at different operating conditions which will be specified by the user

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ACKNOWLEDGEMENTS

I would like to thank my research advisor Dr. Kurt Koelling and graduate student Varun Venoor for the guidance they have given me throughout this project.

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